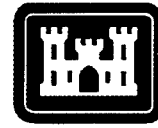


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Geotechnical and Structures
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**US Army Corps
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Engineer Research and
Development Center

Guidelines for Installation of Utilities Beneath Corps of Engineers Levees Using Horizontal Directional Drilling

Carlos A. Latorre, Lillian D. Wakeley, and
Patrick J. Conroy

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Guidelines for Installation of Utilities Beneath Corps of Engineers Levees Using Horizontal Directional Drilling

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Final report

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Preface

The work documented in this report was performed during May through October 2001 as part of the technology transfer component of the Geotechnical Engineering Research Program (GTERP), specifically in the work unit entitled Applications of Trenchless Technology to Civil Works. Funding for preparation and publication of this report was provided by the U.S. Army Corps of Engineers as part of its ongoing support of civil works research. Mr. Carlos Latorre, U.S. Army Engineer Research and Development Center (ERDC), Geotechnical and Structures Laboratory (GSL), is principal investigator for this work unit. The research team also includes Dr. Lillian D. Wakeley, GTERP Manager (ERDC, GSL), Mr. Patrick J. Conroy, U.S. Army Engineer District (USAED), St. Louis (MVS), and Mrs. Nalini Torres (ERDC, GSL). Mr. Jim Chang, CECW, is GTERP Technical Monitor.

The guidelines and specifications provided in this report are based on work completed previously by Dr. R. David Bennett, formerly GSL, ERDC; and Mr. Joseph M. Morones, State of California, Department of Transportation; and modified with their cooperation by Mr. Latorre. This report was prepared by Messrs. Latorre and Conroy and Dr. Wakeley. The authors gratefully acknowledge technical review of this document by Mr. George Sills, USAED, Vicksburg, Mr. Pete Cali, USAED, New Orleans; and Mr. John Wise, USAED, Fort Worth.

This report was completed at ERDC under the general supervision of Dr. Wakeley, Chief, Engineering Geology and Geophysics Branch, Dr. Robert L. Hall, Chief, Geosciences and Structures Division, GSL, and Dr. Michael J. O'Connor, Director, GSL.

At the time of publication of this report, Dr. James R. Houston was Director of ERDC, and COL John W. Morris III, EN, was Commander and Executive Director.

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1 Introduction

Background

Early methods of installing pipelines and utilities across rivers and streams involved excavation of trenches. After the placement of the pipeline, the trenches were backfilled to protect the pipeline from hazards. These early dredged crossings were generally sited at the channel crossing of the thalweg between bends of the river. Here the river is generally a wide, shallow rectangle. This location is chosen because of its hydraulic stability and the economic limitation of the dredging equipment.

In and across the U.S. Army Engineer Division, Mississippi Valley (MVD), lies the heart of the pipeline transmission network of the United States. Hundreds of individual pipelines traverse from Texas and out of the Gulf of Mexico across the numerous rivers, bayous, and wetlands of Louisiana to service the northeast population centers on the Atlantic coast. Along the leveed banks of the lower Mississippi River, pipeline crossings exist between almost every bendway. The crossings of these earthen flood control structures present a difficult and expensive construction problem resulting from concerns about the integrity of the levee which may be subjected to sliding, piping, and erosion failures.

Horizontal Directional Drilling Method

In the early 1970s, a new process was introduced to install pipelines by use of horizontal directional drilling (HDD) techniques acquired from the oil and gas industry. The method has steadily grown to achieve worldwide acceptance and has been used in over 3,000 installations totaling over 1,288 km (800 miles) of pipelines. Today pipeline installations increasingly rely upon HDD technology as the primary method for crossings of watercourses, wetlands, utility corridors, roads, railroads, shorelines, environmental areas, and urban areas.

The placement of pipelines by the HDD method requires the drilling of a guided pilot bore, generally using a 7.3- to 11.43-cm- (2-7/8- to 4-1/2-in.-) diam drill pipe. At the lead, or downhole, end of the pilot string is a fluid powered cutting tool. The cutting tool is either a drill motor to which a bit is connected or a jet bit with nozzles. Drilling fluid is pumped through the string, and fluid causes the motor to rotate which turns the bit to cut the hole. With jet bits, the velocity from the jet nozzle erodes the hole in front of the drill pipe. Located

behind the drill head is a section of the drill pipe with a small bend or angular deviation. This section, known as a bent sub or bent housing, allows the motor or jet nozzle to be directed. A steering tool is latched onto a locking tool on the drill pipe. In this steering tool are a magnetometer and other devices to determine the azimuth, inclination, and orientation of the tool or tool face. Position determinations are made, and the data from the steering tool are plotted in the field to determine the profile and alignment of the bore. Analysis of this position plot is then used to determine drilling progress and path. At a desired location, the pilot drill pipe exits the ground. The pilot bore is then enlarged by pulling reaming tools back through the bore. Once this operation is completed, the pipeline or conduit is attached to the drill pipe and pulled back through the predrilled bore. This is accomplished as the drill pipe is removed, joint by joint, from the drilled path until the pipeline reaches the ground surface at the entry end of the bore.

One of the primary parameters in horizontal directional drilling is the drilling fluid or mud. The drilling mud is usually comprised of a bentonite and water mixture with the main function to power the downhole cutting tool used to open the bore. Secondary functions of the drilling mud are to serve as a lubricant for the pipeline during installation and, in cases of rock or hard ground bores, to remove cuttings from the bore.

The use of HDD has been restricted, in part, by major misunderstandings of how the HDD process actually functions. It is assumed by many that it is similar to well drilling or tunneling in that an open bore is required. This is true only in hard geologic materials such as rock. The majority of HDD pipeline crossings installed to date have been performed in soft ground comprised chiefly of alluvial deposits of silts, sand, and clay. In these types of soils, the process begins with a small pilot bore from which various cutters are inserted to loosen the soil as it is mixed into a slurry by injection of the drilling mud. Once this slurry pathway has been made large enough, generally 25.4 to 30.5 cm (10 to 12 in.) greater than the diameter of the pipeline, the installation of the pipeline commences by pulling the pipeline back through the soft slurry pathway. Some of the in situ soil and fluid are then compressed into the formation, and the remainder of the soil is actually pumped out of the path.

The information in this report represents some of the experiences of the Corps of Engineer (CE) Districts involving HDD for installation of utilities under levees. The experience of the U.S. Army Engineer District (USAED), St. Louis, in dealing with installation of communications systems was identified as having wide applicability to the Corps. Engineering documentation from two St. Louis District projects, the set of guidelines presented in "Installation of Pipelines Beneath Levees Using Horizontal Directional Drilling" (Staheli et al. 1998), Engineer Manual (EM) 1110-2-1913 (Headquarters, Department of the Army (HQDOA) 2000), and the State of California Department of Transportation (CalTrans) Encroachment Permits, "Guidelines and Specifications for Horizontal Directional Drilling Installations" (Morones 2000), provided the basis for this report. A paper on the subject was presented at the Corps Infrastructure Systems Conference in August 2001.

Problem Identification

Although horizontal directional drilling could offer cost-effective, safe alternatives to installing pipelines with open trenching, the CE has no standard guidelines allowing the installation of pipelines with this construction method. As a result, permitting policies are extremely varied and some districts strictly prohibit the use of this technique. While recommended guidelines for pipeline installation using HDD were developed for use by the CE Districts through this work unit back in 1998, as part of a lengthy and detailed EM, the guidelines were not readily recognized by permitting offices as applicable to the questions they face. Also, there is growing pressure on Corps offices particularly by communications companies to install cables under levees.

Objectives

The objectives are to provide and distribute this information to targeted potential users like the CE District permitting offices and engineers that receive applications from utility companies to install utilities under levees. This report addresses those questions and helps CE offices with the growing pressure they are receiving from private companies to allow them to install cables/pipelines under levees. These guidelines are presented in a quick and organized manner that will provide criteria by which to evaluate proposals (e.g., application review, approving, disapproving, and/or making recommendations) for levee crossings, beneath rivers, and within levee rights-of-way using HDD techniques without endangering the levees; and the use of HDD for pipeline installation in areas where the installation technique might be applicable and capable of providing a tremendous cost savings to the Corps of Engineers and the pipeline industry. These guidelines will also help to demonstrate that, very often, these techniques offer substantial economic and operational advantages over current practices. Last but not least, these guidelines will help us stay involved in the development of this fast and fairly new emerging technology.

Potential Benefits

The pipeline industry would realize a tremendous benefit from the use of HDD in crossing of flood control levees. This benefit would include significant cost reduction in construction and maintenance presently required for levees and adjacent road crossings such as bridges, concrete boxes, earthen cover, and ramps. The use of the technique could also benefit the Corps of Engineers by: (a) eliminating blockage of levee crown from buried pipelines, pipeline bridges, or conduit boxes, (b) eliminating differential settlement imposed on levees by the construction of buried pipelines, pipeline bridges, or conduit boxes, (c) improving the operation and safety of grass cutting and other maintenance equipment on the levees, and (d) reducing risk of rupture of pipelines located above or near ground surface on levee slopes, (e) reducing disruption in urban areas, and (f) providing better public acceptance and increasing environmental consciousness.

Potential Problem

While considering any alteration request, the District's prime objective is to protect the integrity of the flood protection systems. In the case of HDD, designers must be aware and take into account during the design stage the following:

- a.* Hydrofracture during installation.
- b.* Preferred seepage path after construction.

To allow third parties to utilize HDD techniques, the District needed methods and processes to prevent these problems from occurring.

2 HDD Guidelines and Specifications

Permit Application Submittal

The permit application package should contain the following information in support of the permit application.

- a.* Location of entry and exit point.
- b.* Equipment and pipe layout areas.
- c.* Proposed drill path alignment (both plan and profile view).
- d.* Location, elevations, and proposed clearances of all utility crossings and structures.
- e.* Proposed depth of cover.
- f.* Soil analysis.
- g.* Product material (HDPE/steel), length, diameter-wall thickness, reamer diameter.
- h.* Detailed pipe calculations, confirming ability of product pipe to withstand installation loads, and long-term operational loads.
- i.* Proposed composition of drilling fluid (based on soil analysis) viscosity and density.
- j.* Drilling fluid pumping capacity, pressures, and flow rates proposed.
- k.* State right-of-way lines, property, and other utility right-of-way or easement lines.
- l.* Elevations.
- m.* Type of tracking method/system.

- n. Survey grid establishment for monitoring ground surface movement (settlement or heave) because of the drilling operation.
- o. Contractor's work plan (see page 11 in this document).

All additional permit conditions shall be set forth in the special provisions of the permit.

Table 1 outlines recommended depths for various pipe diameters:

Table 1	
Recommended Minimum Depth of Cover¹	
Diameter	Depth of Cover
50 mm (2 in.) to 150 mm (6 in.)	1.2 m (4 ft)
200 mm (8 in.) to 350 mm (14 in.)	1.8 m (6 ft)
375 mm (15 in.) to 600 mm (24 in.)	3.0 m (10 ft)
625 mm (25 in.) to 1,200 mm (48 in.)	4.5 m (15 ft)
¹ These depths do not apply for crossing under flood protection projects. (Permission to reprint granted by California Department of Transportation, Office of Encroachment Permits, January 10, 2001).	

The permittee/contractor shall, prior to and upon completion of the directional drill, establish a Survey Grid Line and provide monitoring.

Upon completion of the work, the permittee shall provide an accurate as-built drawing of the installed pipe.

Soil Investigations

A soil investigation should be undertaken. This investigation must be suitable for the proposed complexity of the installation to confirm ground conditions.

Soil analysis

Common sense must be utilized when requiring the extensiveness of the soil analysis. A soil analysis is required in order to obtain information on the ground conditions that the contractor will encounter during the HDD operation.

If the contractor can go to the project site and complete an excavation with a backhoe to 0.03 m (1 ft) below the proposed depth of the bore, that is a soil investigation. In all cases when an excavation is made in creating an entrance and exit pit for an HDD project, that is also an example of a soil investigation. The HDD process is in itself a continual and extensive soil analysis as the pilot bore is made. As the varying soils and formations are encountered, the drilling slurry will change colors, therefore providing the contractor with continual additional information.

The purpose and intent of the soil analysis is to assist the contractor in developing the proper drilling fluid mixture and to ensure the CE and the Levee Board that the contractor is aware of the conditions that do exist in the area of the proposed project. This prepares the contractor in the event they should encounter a zone of pretections and that they would need additives or preventive measures in dealing with inadvertent returns (hydrofractures).

The discretion on the extensiveness of the soil analysis is left to each individual CE District permitting office and/or Levee Board, respectfully, for their respective areas. The HDD inspector/geotechnical engineer plays a large role in assisting the District Permitting Office and Levee Board in making decisions on the extensiveness. Each individual HDD inspector/geotechnical engineer has a general knowledge of the soil conditions in their area of responsibility.

In many circumstances, the soil information has already been prepared, either by the CE District, Levee Board, or by City and County Entities. This information, if available, should be provided to the requesting permittee.

Determination of soil investigations

The CE District Geotechnical Engineer (DGE) should determine the extensiveness of the Soil Investigation to be performed based on the complexity of the HDD operation. DGE may recommend, according to the guidelines listed below, a combination of or modification to the guideline to fit the following respective areas:

- a. Projects less than 152 mm (500 ft) in length, where the product or casing is 20 cm (8 in.) or less in diameter.¹
 - (1) A field soil sampling investigation to a depth of 0.3 m (1 ft) below the proposed drilling.
 - (2) Subsurface strata, fill, debris, and material.
- b. Projects less than 244 m (800 ft) in length, where the product or casing is 36 cm (14 in.) or less in diameter.¹
 - (1) A field soil sampling investigation to a depth of 0.3 m (1 ft) below the proposed drilling.
 - (2) Subsurface strata, fill, debris, and material.
 - (3) Particle size distribution (particularly, percent gravel and cobble).
- c. Projects where the product or casing is 41 cm (16 in.) or greater in diameter. A geotechnical evaluation by a qualified soil engineer is necessary to determine the following:¹

¹ Does not apply when crossing a flood protection project.

- (1) Subsurface strata, fill, debris, and material.
 - (2) Particle size distribution (particularly percent gravel and cobble).
 - (3) Cohesion index, internal angle of friction, and soil classification.
 - (4) Plastic and liquid limits (clays), expansion index (clays), soil density.
 - (5) Water table levels and soil permeability.
- d. Projects where the product or casing is 61 cm (24 in.) or greater in diameter, or when project crosses flood control projects. A geotechnical evaluation by a qualified soil engineer is required to determine the following:
- (1) Subsurface strata, fill, debris, and material.
 - (2) Particle size distribution (particularly, percent gravel and cobble).
 - (3) Cohesion index, internal angle of friction, and soil classification.
 - (4) Plastic and liquid limits (clays), expansion index (clays), soil density, and standard penetration tests.
 - (5) Rock strength, rock joint fracture and orientation, water table levels, and soil permeability.
 - (6) Areas of suspected and known contamination should also be noted and characterized.

Boreholes or test pits should be undertaken at approximately 75- to 125-m (250- to 410-ft) intervals where a proposed installations greater than 305 m (1,000 ft) in length and parallel to an existing road. Additional boreholes or test pits should be considered if substantial variations in soil conditions are encountered.

Should the soil investigation determine the presence of gravel, cobble, and/or boulders, care should be exercised in the selection of drilling equipment and drilling fluids. In such ground conditions, the use of casing pipes or washover pipes may be required or specialized drilling fluids utilized. Fluid jetting methods used as a means of cutting **should only be considered** where soils have a high cohesion such as stiff clays. Jetting should not be allowed when crossing under a flood protection project.

Preconstruction and Site Evaluation

The following steps should be undertaken by the permittee/contractor in order to ensure safe and efficient construction with minimum interruption of normal, everyday activities at the site:

- a. Notify owners of subsurface utilities along and on either side of the proposed drill path of the impending work through USA alert (the one-call program). All utilities along and on either side of the proposed drill path are to be located.
- b. Obtain all necessary permits or authorizations to carry construction activities near or across all such buried obstructions.
- c. Expose all utility crossings using a hydroexcavation, hand excavation, or other approved method (potholing) to confirm depth.
- d. Arrange construction schedule to minimize disruption (e.g., drilling under major highways and/or river crossings).
- e. Determine and document the proposed drill path, including horizontal and vertical alignments and location of buried utilities and substructures along the path.

The size of excavations for entrance and exit pits should be of sufficient size to avoid a sudden radius change of the pipe and consequent excessive deformation at these locations. Sizing the pits is a function of the pipe depth, diameter, and material. All pits, over 1.52 m (5 ft) in depth must abide by Occupational, Safety, and Health Administration (OSHA) regulations.

Prior to commencement of the project, the area should be physically walked over and visually inspected by District Geotechnical Engineer, the driller, and members of the Levee Board for potential entry/exit sites. The following should be addressed:

- a. When on CE/Levee Board property, it should be established whether or not there is sufficient room at the site for: entrance and exit pits; HDD equipment and its safe unimpeded operation; support vehicles; fusion machines; aligning the pipe to be pulled back in a single continuous operation.
- b. Suitability of soil conditions should be established for HDD operations. (The HDD method is ideally suited for soft subsoils such as clays and compacted sands. Subgrade soils consisting of large grain materials like gravel, cobble, and boulders make HDD difficult to use and may contribute to pipe damage.)
- c. The site should be checked for evidence of substructures, such as man-hole covers, valve box covers, meter boxes, electrical transformers, conduits or drop lines from utility poles, and pavement patches. HDD may be a suitable method in areas where the substructure density is relatively high.

Installation Requirements

The permittee shall ensure that appropriate equipment is provided to facilitate the installation: in particular, the drill rig shall have sufficient pulling capacity to meet the required installation loads determined by the detailed pipe calculations. The drill rig should have the ability to provide pull loads, push loads, torque, and the permittee shall ensure that they are monitored during the drilling operation. The permittee shall ensure the drill rod can meet the bend radii required for the proposed installation (a general rule of thumb is 100 times, in feet, the diameter of the installed pipe in inches).

During construction, continuous monitoring and plotting of pilot drill progress shall be undertaken. This is necessary to ensure compliance with the proposed installation alignment and allow for the undertaking of appropriate course corrections that would minimize "dog legs," should the bore begin to deviate from the intended bore path. The actual path of the pilot hole should be plotted against the design drill path.

Monitoring shall be accomplished by manual plotting based on location and depth readings provided by the onboard locating/tracking system or by hand-held walkover tracking systems. These readings map the bore path based on information provided by the locating/tracking system. Readings or plot points shall be undertaken on every drill rod.

For installations where tight control of alignment and grade is required, readings shall be undertaken every 1.0 to 1.5 m (3 to 5 ft). At the completion of the bore, an as-built drawing shall be provided. Prior to commencement of a directional drilling operation, proper calibration of the sonde equipment shall be undertaken.

Monitoring of the drilling fluids such as the pumping rate, pressures at the drill rig and pressures in the annular space behind the drill bit (when drilling under flood control projects), viscosity, and density during the pilot bore, back reaming, and/or pipe installation stages shall be undertaken to ensure adequate removal of soil cuttings and the stability of the borehole is maintained. Excess drilling fluids shall be contained at entry and exit points until recycled or removed from the site. Entry and exit pits should be of sufficient size to contain the expected return of drilling fluids and soil cuttings.

The permittee shall ensure that all drilling fluids are disposed of in a manner acceptable to the appropriate local, state, or federal regulatory agencies. When drilling in contaminated ground, the drilling fluid shall be tested for contamination and disposed of appropriately. Restoration of damage to a levee caused by hydrofracture or any other aspect of the directional drilling operation shall be the responsibility of the permittee. Plans for all restoration or repair work shall be submitted for approval by the Levee District or Corps of Engineers District.

To minimize heaving during pullback, the pullback rate shall be determined by which maximizes the removal of soil cuttings and which minimizes compaction of the ground surrounding the borehole. The pullback rate shall also

minimize overcutting of the borehole during the back reaming operation to ensure that excessive voids are not created and result in postinstallation settlement.

The permittee shall, prior to and upon completion of the directional drill, establish a Survey Grid Line and provide monitoring as outlined in their submitted detailed monitoring plan. Subsurface monitoring points shall be established along the HDD centerline and along any flood protection project that the HDD crosses under to provide early indications of settlement, since large voids may not materialize during drilling as a result of pavement bridging.

Should settlement occur, all repairs would be the responsibility of the permittee. To prevent future settlement should the drilling operation be unsuccessful, the permittee shall ensure the backfill of any void(s) with grout or backfilled by other means. Plans for all restoration or repair work shall be submitted for approval.

Considerations

The following considerations must be taken into account.

- a. Different ground conditions:* The availability of adequate geotechnical information is invaluable in underground construction; it acts to reduce the risk born by the permittee/contractor. However, even in the presence of good geotechnical data, unexpected ground conditions may be encountered. The Contractor's plan should describe the response to different ground conditions.
- b. Turbidity of water and inadvertent returns:* During construction, events like drill bit lockup or being off the design drill path may lead to work stoppage. The permittee/contractor should offer a mechanism to mutually address and mitigate these problems if and when they should arise. For example, contingency plans for containment and disposal of inadvertent returns or hydrofractures.

Permittee/contractor responsibilities

The permittee/contractor should provide the following items: construction plan, site layout plan, project schedule, communication plan, safety procedures, emergency procedures, company experience record, contingencies plan, and drilling fluid management plan.

Construction plan requirements. The permittee shall identify in the construction plan:

- a. Location of entry and exit pits.*
- b. Working areas and their approximate size.*

- c. Proposed pipe fabrication and layout areas.
- d. State right-of-way lines, property lines.
- e. Other utility right-of way and easement lines.
- f. Pipe material and wall thickness.
- g. Location of test pits or boreholes undertaken during the soil investigation.
- h. Identify the proposed drilling alignment (both plan and profile view) from entry to exit.
- i. Identify all grades and curvature radii.
- j. All utilities (both horizontal and vertical).
- k. Structures with their clearances from the proposed drill alignment.
- l. Confirm the minimum clearance requirements of affected utilities and structures.
- m. Required minimum clearances from existing utilities and structures.
- n. Diameter of pilot hole, and number and size of prereams/backreams.
- o. Access requirements to site (if required).
- p. Crew experience.
- q. Type of tracking equipment.

Locating and tracking. The permittee shall describe the method of locating and tracking the drillhead during the pilot bore. Systems include walkover, wire-line, or wireline with wire surface grid. The locating and tracking system shall be capable of ensuring the proposed installation can be installed as intended.

Typical walkover sondes have an effective range of 10 to 15 m, depending on the Electro-magnetic properties of the soil and the extent of local magnetic interference. Depending on the profile of the borehole, the driller may lose contact with the sondes over certain sections of the alignment. As much as practically possible, the sonde should maintain contact with the drill bit. If the "blind" section is expected to be too long or in the vicinity of a buried object, the project engineer may specify the use of a wire-line system or a magnetic navigation tool.

The locating and tracking system shall provide the following information:

- a. Clock and pitch information.
- b. Depth.

- c. Beacon temperature.
- d. Battery status.
- e. Position (x,y).
- f. Azimuth: Where direct overhead readings (walkover) are not possible.

Figure 1 shows a universal housing that will work with any drill-string on all HDD rigs. The placement of the sonde should be before the backreamer. This housing can be utilized in the initial pilot bore. After exiting, the cutting head can be removed and the reamer installed. This housing chamber can utilize any of the sonde batteries manufactured, regardless of manufacturer. There is also a 6-cm (2.5 in.) mini-sonde combination available for smaller rigs.

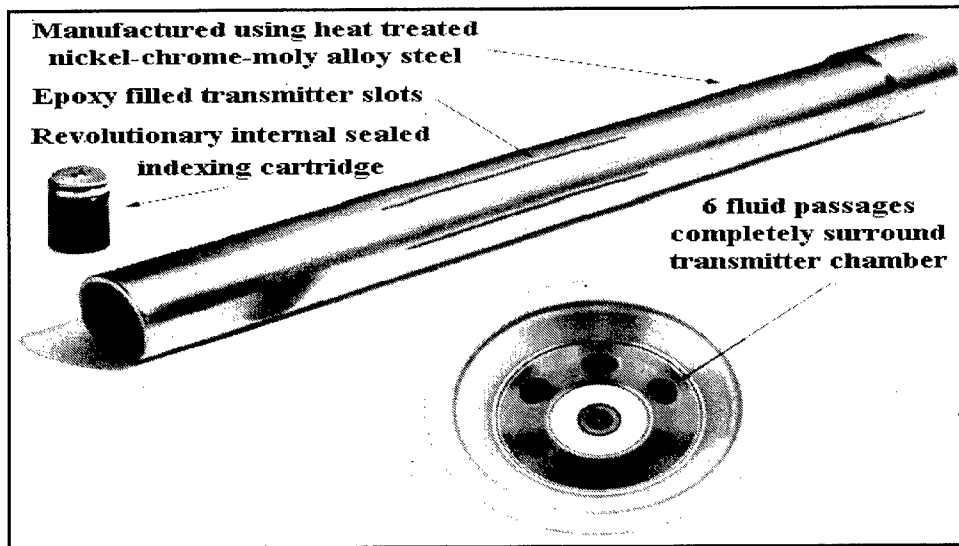


Figure 1. Universal housing for drill-string on HDD rigs (Permission to reprint granted by California Department of Transportation, Office of Encroachment Permits, January 10, 2001)

Drilling fluids management plan. The following information should be provided as part of the drilling fluid management plan. The proposed viscosities for soil transportation to the entry and exit pits are:

- a. Pumping capacity and pressures must be estimated.
- b. Source of fresh water for mixing the drilling mud must be identified. (Necessary approvals and permits are required for sources such as streams, rivers, ponds, or fire hydrants.)
- c. Method of slurry containment must be described and detailed.
- d. Method of recycling drilling fluid and spoils (if applicable) must be explained.

- e.* Method of transporting drilling fluids and spoils offsite must be described.

Drilling fluid pressures in the borehole should not exceed that which can be supported by the foundation soils. Calculation of maximum allowable pressures shall be done for all points along the drill path, taking into account the shear strength of the foundation soils, the depth of the drill path, the bore diameter, and the elevation of the groundwater table. Drilling fluids serve the following functions:

- a.* Remove cuttings from the bottom of the hole and transport them to the surface.
- b.* Hold cuttings in suspension when circulation is interrupted.
- c.* Release cuttings at the surface.
- d.* Stabilize the hole with an impermeable cake.
- e.* Cool and lubricate the drill bit and drill string.
- f.* Control subsurface pressures.
- g.* Transmit hydraulic horsepower.
- h.* Cool the locating transmitter sonde preventing burnout.

Previous experience. The permittee's contractor should provide a list of projects completed by his company, location, project environment (e.g., urban work, river crossing), product diameter, and length of installation. The permittee's contractor should also provide a list of key personnel.

Safety. The drilling unit should be equipped with an electrical strike safety package. The package should include warning sound alarm, grounding mats (if required), and protective gear. The permittee/contractor should have a copy of the company safety manual that includes:

- a.* Operating procedures that comply with applicable regulations, including shoring of pits and excavations when required.
- b.* Emergency procedures for inadvertently boring into a natural gas line, live power cable, water main, sewer lines, or a fiber-optic cable, which comply with applicable regulations.
- c.* Emergency evacuation plan in case of an injury.

Contingency plans. The Contingency plan should address the following:

- a.* Inadvertent return, spill (e.g., drilling fluids, and hydraulic fluids), including measures to contain, clean, and repair the affected area.

- b.* Cleanup of surface seepage of drilling fluids and spoils (i.e., hydrofracture).

Communication plan. The communication plan should address the following:

- a.* The phone numbers for communication with owner or his representative on the site.
- b.* Identification of key person(s) who will be responsible for ensuring that the communications plan is followed.
- c.* Issues to be communicated including safety, progress, and unexpected technical difficulties.

Traffic control.

- a.* When required, the permittee/contractor is responsible for supplying and placing warning signs, barricades, safety lights, and flags or flagmen, as required for the protection of pedestrians and vehicle traffic.
- b.* Obstruction of the roadway, on major road, should be limited to off-peak hours.

Additional Requirements

Information that may be required, include other permits, bonding, and certification as listed in the following sections.

Additional permits

- a.* Obtaining water (i.e., hydrants, streams, etc.)
- b.* Storage, piling, and disposal of material.
- c.* Water/bentonite disposal.
- d.* Any other permits required carrying out the work.

Bonding and certification requirements

- a.* Payment bond (if required).
- b.* Performance bond (if required).
- c.* Certificate of insurance.
- d.* WCB certificate letter.

- e. ACSA certificate of recognition.

Drilling Operations

The following points provide general remarks and rules of thumb related to the directional boring method.

- a. Only operators who have "Proof of Training" by the North American Society of Trenchless Technology (NASTT) should be permitted to operate the drilling equipment in CE/Levee Board property.
- b. Drilling mud pressure in the borehole should not exceed that which can be supported by the foundation soils to prevent heaving or a hydraulic fracturing of the soil (i.e., hydrofracture). Allowing for a sufficient cover depth does not necessarily guarantee against hydrofracture. Sound, cautious drilling practice minimizes the chance of hydrofracture occurrence. Also, measuring mud pressures in the annular space behind the drill bit and comparing these mud pressures with the calculated maximum allowable pressures help minimize the occurrence of hydrofracture. Typical bore depth of 0.75 to 1.0 m gives pipes with an Outside Diameter (O.D.) of 50-200 mm a minimum cover of 0.65 m. While circumstances may dictate greater depths, shallower depths are not recommended.
- c. The drill path alignment should be as straight as possible to minimize the fractional resistance during pullback and to maximize the length of the pipe that can be installed during a single pull.
- d. It is preferable that straight tangent sections be drilled before the introduction of a long radius curve. Under all circumstances, a minimum of one complete length of drill rod should be utilized before starting to level out the borehole path.
- e. The radius of curvature is determined by the bending characteristics of the product line, and it is increasing with diameter.
- f. Entrance angle of the drill string should be between 8 and 20 deg, with 12 deg being considered optimal. Shallower angles may reduce the penetrating capabilities of the drilling rig, while steeper angles may result in steering difficulties, particularly in soft soils. A recommended value for the exit angle of the drill string is within the range of 5 to 10 deg.
- g. Whenever possible, HDD installation should be planned so that back reaming and pulling for a leg can be completed on the same day. If necessary, it is permissible to drill the pilot hole and preream one day, and complete both the final ream and the pullback on the following day.
- h. If a drill hole beneath a levee must be abandoned, the hole should be backfilled with grout or bentonite to prevent future subsidence.

- i.* Pipe installation should be performed in a manner that minimizes the over-stressing and straining of the pipe. This is of particular importance in the case of a polyethylene pipe.

Equipment setup and site layout

- a.* Sufficient space is required on the rig side to safely set up and operate the equipment. The workspace required depends on the type of rig to be used. A small rig may require as little as 3- by 3-m working space, while a large river crossing unit requires a minimum of 30- by 50-m working area. A working space of similar dimensions to that on the rig side should be allocated on the pipe side, in case there is a need to move the rig and attempt drilling from this end of the crossing.
- b.* If at all possible, the crossing should be planned to ensure that drilling proceed downhill, allowing the drilling mud to remain in the hole, minimizing inadvertent return.
- c.* Sufficient space should be allocated to fabricate the product pipeline into one string, thus enabling the pullback to be conducted in a single continuous operation. Tie-ins of successive strings during pullback may considerably increase the risk of an unsuccessful installation.

Drilling and back-reaming

- a.* Drilling mud should be used during drilling and back reaming operations. Using water exclusively may cause collapse of the borehole in unconsolidated soils. While in clays, the use of water may cause swelling and subsequent jamming of the product.
- b.* Heaving may occur when attempting to back-ream a hole that is too large. This can be avoided by using several prereams to gradually enlarge the hole to the desired diameter.
- c.* A swivel should be included between the reamer and the product pipe to prevent the transfer of rotational torque to the pipe during pullback.
- d.* In order to prevent over stressing of the product during pullback, a weak link, or break-away pulling head, may be used between the swivel and the leading end of the pipe. More details regarding breakaway pulling heads can be found in paragraph entitled "Break-away Pulling Head."
- e.* The pilot hole must be back-reamed to accommodate and permit free sliding of the product inside the borehole. A rule of thumb is to have a borehole 1.5 times the outer diameter of the product. This rule of thumb should be observed particularly with the larger diameter installations (≥ 250 -mm O.D.). Some recommended values for final preream diameter

as a function of the product O.D. are given in Table 2. These values should be increased by 25 percent if excessive swelling of the soil is expected to occur or the presence of boulders/cobbles is suspected.

- f. The conduit must be sealed at either end with a cap or a plug to prevent water, drilling fluids, and other foreign materials from entering the pipe as it is being pulled back.
- g. Pipe rollers, skates, or other protective devices should be used to prevent damage to the pipe from the edges of the pit during pullback, eliminate ground drag, or reduce pulling force and subsequently reduce the stress on the product.
- h. The drilling mud in the annular region should not be removed after installation but permitted to solidify and provide support for the pipe and neighboring soil.

Table 2 Recommended Back-Ream Hole Diameter (after Popelar et al. 1997)	
Nominal Pipe Diameter, mm	Back-Ream Hole Diameter, mm
50	75 to 100
75	100 to 150
100	150 to 200
150	250 to 300
200	300 to 350
250	350 to 400
≥300	At least 1.5 times product OD

Drilling Fluid - Collection and Disposal Practices

The collection and handling of drilling fluids and inadvertent returns, along with the need to keep drilling fluids out of streams, streets, and municipal sewer lines, have been among the most debated topics. These points include:

- a. Drilling mud and additives to be used on a particular job should be identified in the permit package, and their Material Safety Data Sheets (MSDS) should be provided to the Permit Office.
- b. Excess drilling mud slurry shall be contained in a lined pit or containment pond at exit and entry points, until recycled or removed from the site. Entrance and exit pits should be of sufficient size to contain the expected return of drilling mud and spoils.
- c. Methods to be used in the collections, transportation, and disposal of drilling fluids, spoils, and excess drilling fluids should be in compliance with local ordinances, regulations, and environmentally sound practices in an approved disposal site.

- d. The slurry should be tested for contamination and disposed of in a manner which meets government requirements when working in an area of contaminated ground.
- e. Precautions should be taken to keep drilling fluids out of the streets, manholes, sanitary and storm sewers, and other drainage systems, including streams and rivers.
- f. Recycling drilling fluids is an acceptable alternative to disposal.
- g. All diligent efforts should be made by contractor to minimize the amount of drilling fluids and cuttings spilled during the drilling operation, and complete cleanup of all drilling mud overflows or spills shall be provided.

There are legitimate concerns associated with the fluid pressures used for excavation during the horizontal directional drilling process and the risk of hydraulic fracturing. Reasonable limits must be placed on maximum fluid pressures in the annular space of the bore to prevent inadvertent drilling fluid returns to the ground surface. However, it is equally important that drilling pressures remain sufficiently high to maintain borehole stability, since the ease in which the pipe will be inserted into the borehole is dependent upon borehole stability. Limiting borehole pressures are a function of pore pressure, the pressure required to counterbalance the effective normal stresses acting around the bore (depth), and the undrained shear strength of the soil.

Tie-Ins and Connections

Trenching may be used to join sections of conduits installed by the directional boring method. An additional pipe length, sufficient for joining to the next segment, should be pulled into the entrance pit. This length of the pipe should not be damaged or interfere with the subsequent drilling of the next leg. The contractor should leave a minimum of 1 m of conduit above the ground on both sides of the borehole.

Alignment and Minimum Separation

The product should be installed to the alignment and elevations shown on the drawings within the prespecified tolerances (tolerance values are application dependent, for example, in a major river crossing, a tolerance of ± 4 m from the exit location along the drill path center line may be an acceptable value). This tolerance is not acceptable when installing a product line between manholes. Similarly, grade requirements for a water forcemain are significantly different from those on a gravity sewer project.

When a product line is installed in a crowded right-of-way, the issue of safe minimum separation distance arises. Many utility companies have established regulations for minimum separation distances between various utilities. These

distances needed to be adjusted to account for possible minor deviation when a line product is installed using HDD technology. As a rule of thumb, if the separation distance between the proposed alignment and the existing line is 5 m or more, normal installation procedures can be followed. If the separation is 1.5 m or less, special measures, such as observation boreholes are required. The range between 1.5 and 5 m is a “gray” area, typically subject to engineering judgment (a natural gas transmission line is likely to be treated more cautiously than a storm water drainage line).

Break-Away Pulling Head

Recent reports from several natural gas utility companies reveal concerns regarding failure experienced on HDPE pipes installed by horizontal directional drilling. These failures were attributed to deformation of the pipe due to the use of excessive pulling force during installation. A mitigation measure adopted by some gas companies involves the use of break-away swivels to limit the amount of force used when pulling HDPE products. Some details regarding these devices and their applications are given below.

- a. The weak link used can be either a small diameter pipe (but same SDR) or specially manufactured break-away link. The latter consists of a breaking pin with a defined tensile strength incorporated in a swivel. When the strength of the pin is exceeded it will break, causing the swivel to separate. A summary of pulling head specifications is given in Table 3 (all products are SDR 11). Note that the values provided in Table 3 could be considered conservative.

Table 3		
Pulling Head Specifications		
Pipe Diameter (in.)¹	Diameter of Break-Away Swivel (in.)	Maximum Allowable Pulling Force (lb)²
1-1/4	7/8	850
2	1-1/4	1,500
4	1 3/8	5,500
6	2-1/2	12,000
8	3	18,500
¹ To convert inches to centimeters, multiply by 2.54.		
² To convert pounds to kilograms, multiply by 0.4535.		

- b. The use of break-away swivels is particularly warranted when installing small diameter HDPE pipes (up to 10-cm (4 in.) O.D.). Application of such devices in the installation of larger diameter products is not currently a common practice.
- c. If the drilling equipment-rated pulling capacity is less than the safe load, the use of a weak link may not be required.

- d. Exceeding the product elastic limit can be avoided simply by following good drilling practices, namely: regulating pulling force; regulating pulling speed; proper ream sizing; and using appropriate amounts of drilling slurry fluid.

Protective Coatings

In an HDD installation, the product may be exposed to extra abrasion during pullback. When installing a steel pipe, a form of coating which provides a corrosion barrier as well as an abrasion barrier is recommended during the operation, the coating should be well bonded and have a hard smooth surface to resist soil stresses and reduce friction, respectively. A recommended type of coating for steel pipes is mill applied Fusion Bonded Epoxy.

Site Restoration and Postconstruction Evaluation

All surfaces affected by the work shall be restored to their preconstruction conditions. Performance criteria for restoration work will be similar to those employed in traditional open excavation work. If required, the permittee/contractor shall provide a set of as-built drawings including both alignment and profile. Drawings should be constructed from actual field readings. Raw data should be available for submission at any time upon request. As part of the "As-Built" document, the contractor shall specify the tracking equipment used, including method or confirmatory procedure used to ensure the data were captured.

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Appendix A

Recommended Guidelines for Installation of Pipelines Beneath Levees Using Horizontal Directional Drilling¹

The guidelines for the installation of pipelines using horizontal directional drilling are based on the results and conclusions of the field evaluation of the Construction Productivity Advancement Research (CPAR) project, Installation of Pipelines Beneath Levees using Horizontal Directional Drilling (HDD), as well as analytical studies of soil/drilling fluid interaction and evaluation of case history data. The recommended guidelines are appropriate for projects on which the Corps of Engineers (CE) has jurisdiction and may be used for non-CE projects, as well. The recommendations address the main issues of concern that have been expressed by CE District personnel, either in District regulations or in meetings and discussions. References are listed at the end of this appendix.

With each proposed crossing, it is important that the critical elements of the HDD process are addressed to enhance the possibilities of a successful levee crossing. Addressing each element will greatly reduce the risk of creating preferential seepage paths or other phenomena that threaten the stability of the levee. Key elements addressed in this guideline include:

- a.* Establishing allowable drilling fluid pressures.
- b.* Monitoring drilling fluid pressures.
- c.* Establishing appropriate setback distances.
- d.* Establishing appropriate depths of cover over the pipeline.
- e.* Controlling speed of drilling.

¹ Staheli, K., Bennett, R. D., O'Donnell, H. W., and Hurley, T. J. (1998). "Installation of pipelines beneath levees using horizontal directional drilling," Technical Report CPAR-GL-98-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

- f. Evaluating effects of groundwater.
- g. Prevention of seepage and erosion.
- h. Use of disclosure devices.
- i. Use of relief wells.

When establishing the appropriate parameters for each project, it is important to have accurate geotechnical information. Many of the key parameters for a project, including limiting pressures, setback distances, and depth of cover, depend on soil properties and geotechnical data gathered during preconstruction geotechnical investigations or collected during construction of the levee. Without accurate soil investigation data, it will be difficult to determine appropriate drilling parameters and could result in inappropriate design.

Allowable Drilling Fluid Pressures

There are legitimate concerns associated with the fluid pressures used for excavation during the horizontal directional drilling process and the risk of hydraulic fracturing. Reasonable limits must be placed on maximum fluid pressures in the annular space of the bore to prevent inadvertent drilling fluid returns to the ground surface. However, it is equally important that drilling pressures remain sufficiently high to maintain borehole stability, since the ease in which the pipe will be inserted into the borehole is dependent upon borehole stability. Limiting borehole pressures are a function of pore pressure, the pressure required to counterbalance the effective normal stresses acting around the bore (depth), and the undrained shear strength of the soil.

Maximum allowable mud pressures

To establish the maximum allowable mud pressure, Delft Geotechnics (1997) has suggested use of the following equation which is based on cavity expansion theory (Appendix B in Staheli, Bennett, O'Donnell, and Hurley 1998):

$$P_{lim} = (P_f + c \cdot \cot \phi) \left(Q \right)^{\frac{-\sin \phi}{1+\sin \phi}} \left\{ \left(\frac{R_o}{R_{p,max}} \right)^2 + Q \right\}^{\frac{-\sin \phi}{1+\sin \phi}} - c \cdot \cot \phi \quad (A1)$$

where

P_{lim} = limiting mud pressure

P_f = mud pressure at onset of plastic failure

$$P_f = \sigma'_0 (1 + \sin \phi) + c(\cos \phi)$$

σ'_0 = initial effective stress

c = effective cohesion

ϕ = effective internal angle of friction

Q = a function of the shear modulus and effective stress

$$Q = \frac{\sigma'_0(\sin \phi) + c(\cos \phi)}{G}$$

G = shear modulus

R_0 = initial radius of the borehole

$R_{p,max}$ = radius of the plastic zone

However, the cavity expansion theory is based on an infinite plastic zone. The equation given by Delft Geotechnics depends on the determination of a "safe radius" ($R_{p,max}$) around the borehole in which the drilling mud will remain, also referred to as the maximum allowable radius of the plastic zone. The equation determines the pressure that would cause drilling fluid to exit the maximum radius of the plastic zone. For the determination of the maximum radius of the plastic zone, Delft Geotechnics suggests using a value of $H/2$ for clay soils and $2/3 H$ for sandy soils, where H represents the height of soil cover over the pipeline. Using this equation along with values for the internal angle of friction, the shear modulus of the soil, and the initial pore pressure, the maximum allowable mud pressure can be determined over the length of the bore. Figure A1 shows limiting mud pressures as a function of depth for a typical sand and soft clay. For these calculations, it was assumed that the water table was located at the ground surface. The values used in the calculation for limiting pressure are listed in Table A1. From Figure A1, it is easily seen that with the cavity expansion theory the limiting pressures in a sandy material are much higher than in a clay material, except for very shallow depths. This is largely a result of the functional properties exhibited by the sand, which inhibits cavity expansion.

For the six borings, the following tests were made on selected soil samples: wet and dry unit weight, unconfined compressive strength, Atterberg limits, moisture contents, and sieve tests.

Figure A2 shows the maximum allowable mud pressures determined for the CPAR field test. From this figure it is easily seen that the maximum allowable pressure varies with the depth of soil cover. Based on these calculations, it would be necessary for the pressure in the annular space of the bore to remain below the maximum allowable pressure throughout the drilling process to minimize the potential for initiating plastic yield and losing drilling mud to the surface.

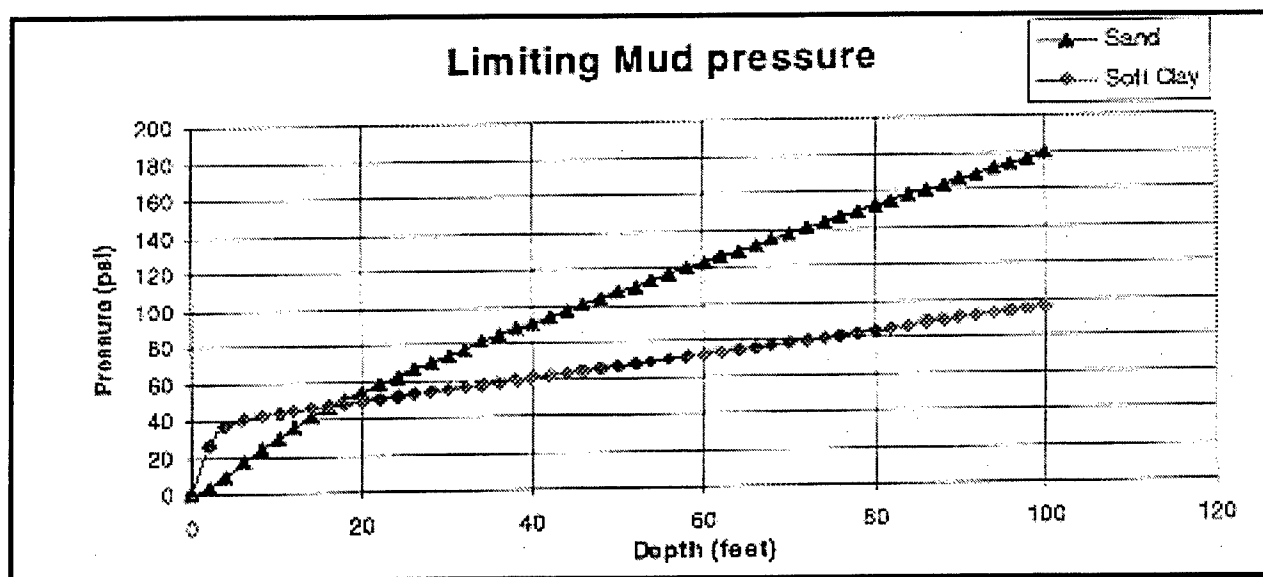


Figure A1. Limiting mud pressure, sand, and soft clay. (To convert feet to meters, multiply by 0.305; to convert psi to kN/m^2 , multiply by 6.89)

Table A1 Soil Properties Used for Calculating Limiting Drilling Fluid Pressures				
Soil Type	Friction Angle Radians (deg)	Shear Modulus kg/m^2 (ksf)	Cohesion kN/m^2 (psf)	Unit Weight kg/m^3 (pcf)
Sand	0.51 (30)	488,431 (100)	0	1,921 (120)
Soft clay	0	122,108 (25)	2,442 (500)	1,601 (100)

Although the maximum allowable or limiting mud pressures were exceeded on the entry side of the levee, no inadvertent returns were identified because the excess pressures were dissipated through the borehole at the entry location. On the riverside of the levee, inadvertent returns were observed within 12.2 m (40 ft) of the exit location. From Figure A2, it can be seen that the inadvertent returns occurred in a zone where the drilling pressure in the annular space, which remained fairly constant at a pressure of 344.5 kN/m^2 (5 psi), exceeded the maximum allowable mud pressure.

Minimum required mud pressures

Although it is important to establish an upper bound to the pressure, it is equally important to understand that unreasonably low borehole pressures cannot be maintained without severely hindering the drilling process and, in some cases, making the pipe installation impossible. The drilling mud pressure must be maintained above the groundwater pressure to prevent collapse of the borehole.

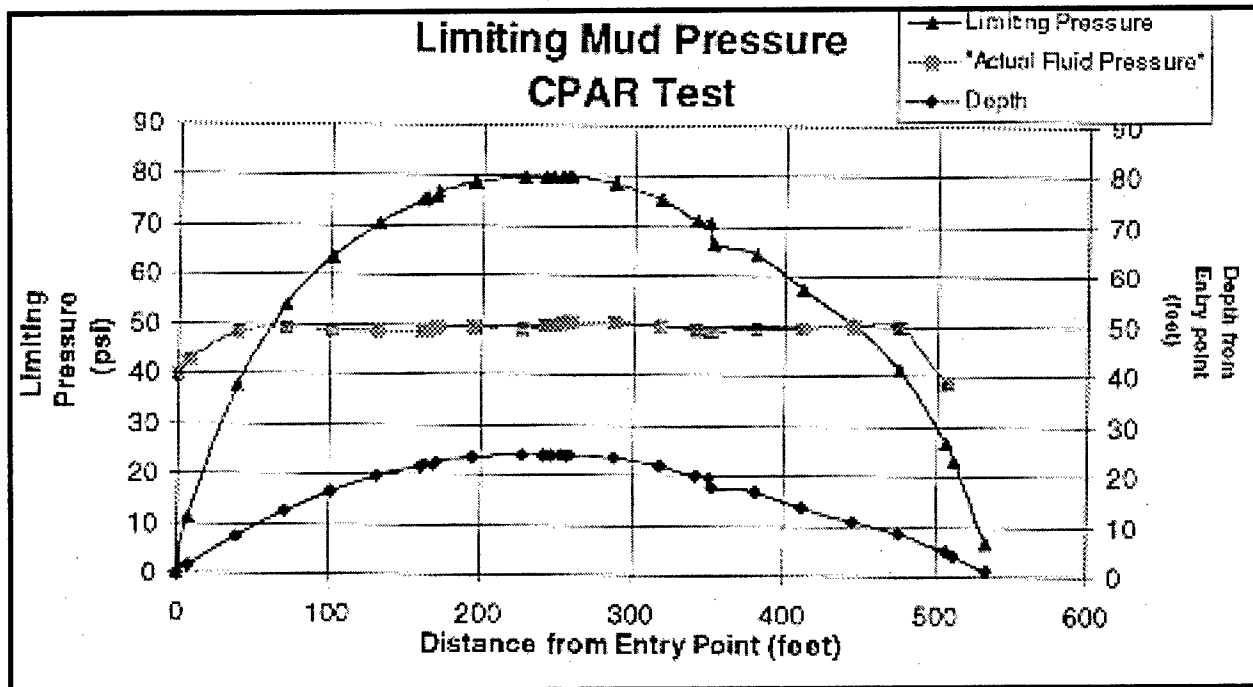


Figure A2. Limiting mud pressure, CPAR test. (To convert feet to meters, multiply by 0.305; to convert psi to kN/m², multiply by 6.89)

The pressure in the bore resulting from the weight of the chilling mud is calculated with Equation A2.

$$P_1 = h * \gamma_{\text{mud}} \quad (\text{A2})$$

where

P_1 = component of minimum required annular pressure provided by mud weight

h = difference in elevation between the bore and the exit point of the mud flow

γ_{mud} = unit weight of mud

An additional component of the minimum required mud pressure is that required to start the flow of the mud with the cuttings in the bore. This component is relatively small and can be considered a threshold pressure since it is only required to start flow, not to maintain the flow of the drilling mud and the cuttings. Therefore, for simplicity, the minimum required mud pressure can be estimated with Equation A2. For the CPAR project, the average mud unit weight was 11.5 kN/m³ (73 lb/ft³). Figure A3 shows the minimum and maximum allowable or limiting pressures along the length of the bore.

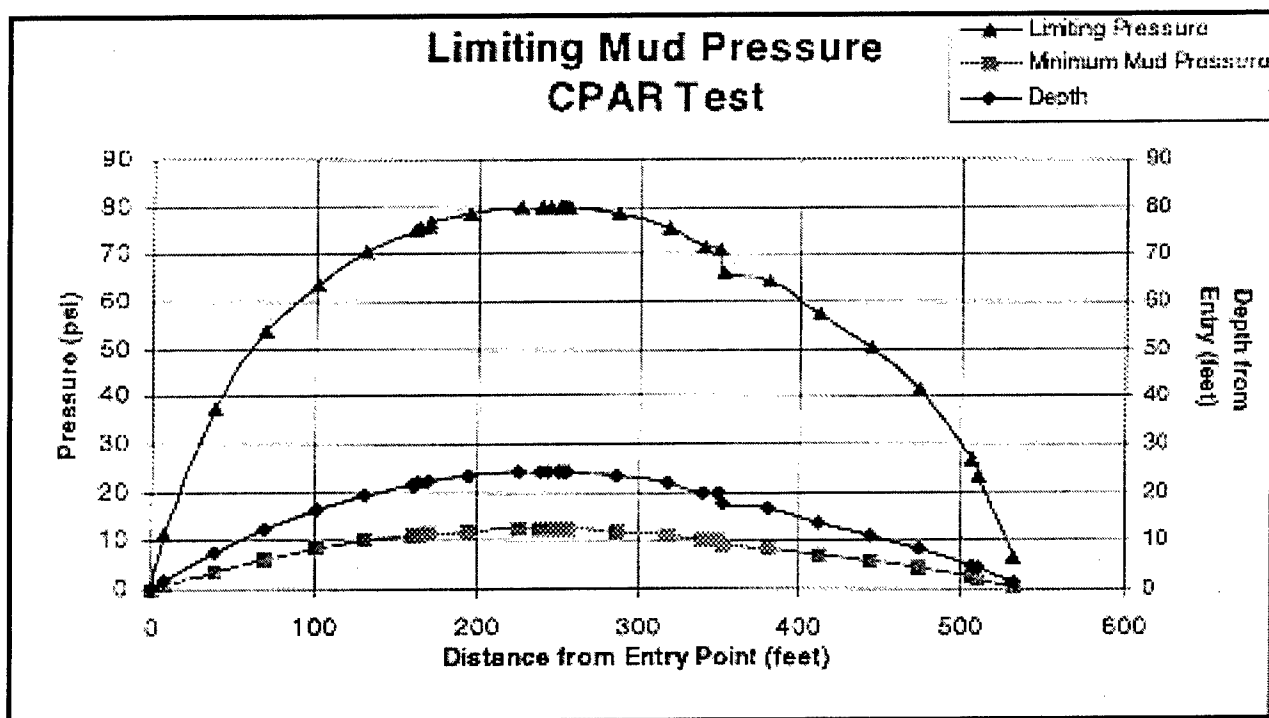


Figure A3. Limiting mud pressure, CPAR test, minimum and maximum pressure. (To convert feet to meters, multiply by 0.305; to convert psi to kN/m², multiply by 6.89)

During the drilling process, the required minimum pressure will vary with the groundwater head and overburden pressure. In addition, the threshold pressure required to get the fluid moving in the borehole will vary with mud weight.

Monitoring Drilling Fluid Pressures

During the drilling process, the pressure in the borehole must be monitored to ensure that the operational drilling pressures remain within the safe limits, as calculated with the recommended methods. It is common practice to have a pressure gauge located at the mud pump to measure mud pressures within the drilling stem. However, there is a significant amount of head loss as a result of the flow through the drill stem and the rotational movement of the drilling mud caused by the abrupt change in flow direction as it exits the drilling stem into the annular space. The most common method for establishing the limiting pressure is to estimate the head loss and control the operational pressures, as measured at the pump. However, the actual head loss is very difficult to quantify, and estimates on the head loss may lead to the establishment of limiting pressures that are not consistent with the actual conditions.

Instead of monitoring the pressure in the drill stem and estimating the head losses through the drill stem and nozzles, it is highly recommended to monitor the pressure in the annular space, since the pressure in the borehole ultimately affects the stability of the bore. It is recommended that an external pressure-measuring device, such as the device used on the CPAR project, be required on all projects when drilling beneath flood control structures. Readings provided by

a down-hole pressure sensor can be used to monitor the limiting drilling pressures and ensure that the maximum allowable pressure is not exceeded. In addition, pressures should be monitored and recorded at the drill stem and in nearby piezometers, as on the CPAR project, to monitor the radial effect of the drilling process. Monitoring should include pre- and postconstruction readings of piezometers to establish a baseline pressure and ensure that any excess pressures resulting from the drilling process dissipate. The contractor should be required to submit plans for monitoring and controlling drilling fluid pressures and for avoiding inadvertent returns. The limiting pressures should be estimated prior to construction and clearly stated in the contract documents or in the contractor submittals. The submittal requirements should include daily logs of pressure measurements and locations at frequent intervals.

Setback Distances

Determination of appropriate setback distances can be very important with respect to damage of the levee toe and seepage and uplift pressures at the point where the top stratum is penetrated by the drill string. Levee toe stability is not the controlling factor under normal circumstances but should be checked in the design as a precaution. However, seepage is a significant concern and must be addressed on a case-by-case basis, because seepage is highly dependent on levee geometry, high water level, the material of the top stratum, and the material in the substratum.

Examples of the current District Regulation 1130-2-303 (U.S. Army Engineer District, Vicksburg 1993) are summarized below with respect to setback distances:

- a. *Case 1.* If construction plans and specifications are not supported by borings made at the project site, the pipeline must be at its maximum depth at least 91.4 m (300 ft) landside from the center line of the levee on the landside.
- b. *Case 2.* If plans are supported by borings at the project site, the drill rig must penetrate the substratum at least 91.4 m (300 ft) from the levee center line on the landside and must not exit the substratum or penetrate the top stratum any closer than 91.4 m (300 ft) riverside of the levee center line (U.S. Army Engineer District, Vicksburg 1993).

The original field memorandum, written in 1988 after the Atchafalaya Project (Wells and Kemp 1981), recommended a setback distance of 91.4 m (300 ft). This document apparently established the baseline for the regulations established by the U.S. Army Engineer Districts, Vicksburg and New Orleans. However, these restrictions were established on the observations of one project where suspect drilling conditions and procedures led to significant problems. These unfavorable conditions and procedures should be avoided, and the problems observed on this project may not be prudent concerns in all cases. It is more reasonable to establish setback distances based on rational seepage analyses by

using measured soil properties and engineering characteristics determined from prudent geotechnical investigations.

Levee toe stability

The tests conducted by ERDC and those conducted by Delft Geotechnics (Luger and Hergarden 1988) clearly showed that external drilling pressures do not pose a serious concern for levee stability if the pipeline is designed at an appropriate depth, proper drilling procedures are employed, and drilling pressures are monitored accordingly. When designing the depth of the pipeline, it is important to consider that the drilling fluid pressures may well exceed the maximum allowable drilling fluid pressure near the entry and exit locations due to the shallow depths, resulting in limited inadvertent returns. Because reasonable fluid pressures must be maintained to initiate and complete the bore, "excessive" pressures are necessary in these shallow zones. Therefore, the entry and exit locations should be located such that these zones do not threaten the safety of the levee.

Penetration of the top stratum

To address seepage and uplift concerns, it is critical to consider each levee crossing on a case-by-case basis because the seepage is highly dependent on soil properties and geometry. A parametric study was performed using the LEVEEMSU programs (Gabr et al. 1995) to establish a basis for approximate setback distances. The hydraulic gradient at the toe was recorded, as was the distance where the hydraulic gradient approached zero, signifying no concerns for seepage or uplift. The results were highly dependent on the difference between permeability of the top stratum and the substratum on the landside of the levee. As the permeability of the top stratum approached the permeability of the pervious substratum, the location where the hydraulic gradient approached zero became closer to the toe. This is because the excess pore pressure can be dissipated through the pervious top stratum instead of "transferring" the pressure to a location where dissipation is possible (farther from the levee toe). Although use of a low permeability blanket increases the distance from the toe at which the gradient approaches zero. Consequently, the maximum allowable gradient criterion should not be used alone to establish setback distances.

The LEVEEMSU program (Wolff 1989) was used to analyze levee underseepage and to define reasonable setback distances. LEVEEMSU analysis algorithms are based on a numerical analysis of the flow domain and geometric conditions. The solution algorithm was based on the use of a finite difference formulation to model the steady-state flow domain. In this analysis, a two-layer model was created, with seepage flow assumed to be horizontal in the substratum and vertical in the top blanket. Hydraulic heads and gradients were computed as a function of horizontal location.

For this parametric study, LEVEEMSU calculated the hydraulic gradient at the levee toe and the horizontal distances from the levee toe to where the hydraulic gradient was equal to 0.6 and where it was effectively zero. The layer

permeabilities and the geometric properties varied over a series of 12 computations. In the first eight computations, a 15.3-m- (50-ft-) thick substratum and a 0.6-m- (2-ft-) thick top blanket was used. The water level was 5.2 m (17 ft) above the top blanket. The eight runs were produced by combining four substratum permeability values, ranging from 4×10^{-5} to 4×10^{-2} cm/sec, with two top-blanket permeability values, 1×10^{-5} cm/sec and 1×10^{-4} cm/sec. For the final four computations, the same four substratum permeability values were used with a top-blanket permeability of 1×10^{-5} cm/sec. The thickness of the substratum was changed to 14.3 m (47 ft), and the top blanket was increased to 1.5 m (5 ft) in thickness. The water level was kept at 5.2 m (17 ft) above the top blanket.

The results of this small study show that the layer thickness is not a critical factor in the resulting hydraulic gradient; however, the permeability values are significant. For all three sets of four computations, the same trend is observed: as substratum permeability decreases, the hydraulic gradient at the toe and the two recorded distances also decreases. Since this analysis involves the steady-state flow domain, it is not only the actual permeability values that account for this trend, but it is also the difference in order of magnitude between the top-blanket and substratum permeabilities. When comparing different runs which have the same difference in order of magnitude for the top stratum and substratum permeabilities, similar or identical distances were calculated. Table A2 details the results from the parametric study.

Table A2 Results of Parametric Study					
Top-Blanket Vertical Permeability	Substratum Horizontal Permeability	Top-Blanket Thickness m (ft)	Hydraulic Gradient at Levee Toe	Location where Hydraulic Gradient = 0.6 m (ft)	Location where Hydraulic Gradient = 0 m (ft)
1×10^{-5}	4×10^{-2}	0.6 (2)	6.0	305.0 (1,000)	549.0 (1,800)
1×10^{-5}	4×10^{-3}	0.6 (2)	3.8	106.8 (350)	244.0 (800)
1×10^{-5}	4×10^{-4}	0.6 (2)	1.1	7.6 (25)	21.4 (70)
1×10^{-5}	4×10^{-5}	0.6 (2)	0.3	—	7.6 (25)
1×10^{-4}	4×10^{-2}	0.6 (2)	3.8	106.8 (350)	244.0 (800)
1×10^{-4}	4×10^{-3}	0.6 (2)	1.9	22.9 (75)	61.0 (200)
1×10^{-4}	4×10^{-4}	0.6 (2)	0.7	7.6 (25)	15.3 (50)
1×10^{-4}	4×10^{-5}	0.6 (2)	0.1	—	7.6 (25)
1×10^{-5}	4×10^{-2}	1.5 (5)	2.5	305.0 (1,000)	549.0 (1,800)
1×10^{-5}	4×10^{-3}	1.5 (5)	1.8	106.8 (350)	244.0 (800)
1×10^{-5}	4×10^{-4}	1.5 (5)	1.0	15.3 (50)	68.6 (225)
1×10^{-5}	4×10^{-5}	1.5 (5)	0.4	—	15.3 (50)

The results of the parametric study clearly show that the permeability of the substratum and top blanket are of critical importance when establishing a minimum setback distance. For projects with site conditions like the CPAR project, where the top and bottom strata were very similar materials with relatively high permeabilities, the computed minimum setback distance may be very low. This condition results, as noted previously, because the excessive pressures and high gradients dissipate rapidly when there is little contrast in hydraulic conductivity between the top and substrata. However, if a larger contrast exists between top stratum and substratum permeabilities, the computed setback distances may be

quite high. At a minimum, it is recommended that the pipeline should not penetrate any term of the levee on either side. In cases where the difference in permeabilities between the top and bottom strata are several orders of magnitude apart, it is important to establish a reasonable distance where seepage and uplift pressures will have negligible effects on levee stability. For example, if the seepage calculations show that a setback distance of 549 m (1,800 ft) is required, one must consider if seepage 152.4 m (500 ft) (or less) from the levee would be of any concern to safety and performance of the levee.

Depth of cover

The minimum depth of cover should be established by the calculations for maximum borehole pressures and a comparison of those pressures and reasonable drilling pressures. In the case where the reasonable operational drilling pressure exceeds the maximum drilling pressure, the pipeline should be set at a deeper elevation to raise the maximum drilling pressure. Establishing a minimum setback distance at which the maximum depth of the bore is reached prior to the center line of the levee should not be necessary as long as drilling pressures are closely monitored and remain within the established limiting pressures.

Speed of drilling

The speed of drilling (rate at which the pipe string or pipeline is advanced through the ground) should be controlled for several reasons. It may be difficult to maintain the planned line and grade if the advance rate is extremely high. If the drill veers offline because of the advance rate, the driller may decide to pull back a section and redrill for position. The U.S. Army Engineer Research and Development Center (ERDC), Construction Productivity Advancement Research (CPAR) tests clearly showed that redrilling caused localized pressure bulbs that resulted in increased drilling pressures over longer time periods compared to one-pass drilling. Redrilling for position may be necessary; however, it is recommended that advance rates be limited as a preventative measure against pressure buildup. It is extremely important to adjust the flow rate of the drilling mud when changing the speed of the drilling operation. This will limit the possibility of over pressurizing the borehole as a result of the total volume of mud that is pumped per drill pipe section.

Groundwater

The results of the CPAR tests indicated that the presence of groundwater decreased the potential for inadvertent returns to the surface, as no fracturing was observed below the water table on the project. This results from the fact that the pipeline was constructed primarily in noncohesive soils. Noncohesive soils do not exhibit tensile strength. As a result, tension cracks cannot propagate through the soil mass. In addition, the groundwater pressures tend to counterbalance drilling fluid pressures and reduce the potential for hydrofracture. The beneficial effect may not be realized in clay soils, because they may exhibit tensile strength in the saturated or partially saturated state. However, even in clay soils, the

presence of groundwater will serve to heal old desiccation cracks that would provide a potential flow path for the pressurized drilling fluid. When practical, it is recommended that the design depth of the pipeline should remain below the water table when drilling within a lateral distance of 7.6 m (25 ft) of the levee toe.

Prevention of seepage and erosion along pipeline

The directional drilling process creates a borehole that is approximately 0.305 m (1 ft) larger in diameter than the installed pipeline. The oversized borehole is necessary to allow the pipeline to be pulled back from the exit side of the crossing without exceeding the tensile strength of the pipe and drilling stem or the pullback capacity of the drill rig. The borehole is kept filled with a fluid mixture of bentonite, water, and excavated soil during the entire process of pilot hole drilling, reaming, and pullback. The drilling fluid-soil mixture, which is comprised partially of sodium montmorillonite clay mineral, has a very low coefficient of permeability.

Concerns have been expressed about the potential for development of preferential seepage pathways along the pipeline annulus during flooding or high water stages. It has been suggested that the high hydrostatic head and gradients could cause the drilling fluid and soil mixture to be flushed from the annular space. Seepage flows around the pipeline could produce high-seepage velocities resulting in soil erosion and development of boils on the landside at the point where the HDD-installed pipeline penetrated the ground. Worst-case scenario would be failure of the levee system and catastrophic flooding. Depending on the drilling mud-soil mixture around the pipeline, it may not be possible to displace the material in the annulus; however, these concerns can be addressed in design and construction. The recommendations presented below focus on the design and construction measures that have been suggested by various individuals to minimize or eliminate the potential for unacceptable seepage along the pipeline. These measures include:

- a. Grouting of annular space and minimizing annular space.
- b. Landside seepage blankets or berms.
- c. Riverside cutoffs or collars (applicable only for pipelines that exit or enter the riverside of levee).

Grouting of annular space

Grouting of the annular space with a cement or bentonite-cement grout mixture has been suggested or required on some pipeline crossings. The objective has been to expel the semifluid mixture of bentonite, soil, and water with a grout material that will set and provide a solid barrier against seepage flow along the annulus. One possibility is that a grout mixture with a delayed set time be pumped into the hole during the final reaming and pullback of the pipe to more effectively displace the bentonite-based drilling mud mixture. It is argued that

this process would reliably and completely expel the drilling fluid and replace it with grout.

The proposal for grouting during pullback reduces the risks of future development of seepage pathways. However, the risks of failure to complete the pipeline installation could be high. If, for any reason, the pullback was delayed beyond the initial set time, the partially installed pipeline could become grouted in place. Substantial financial loss would be incurred by the pipeline company and/or contractor. In addition, the problem of a partially installed pipeline would have to somehow be mitigated.

The field research performed under the CPAR program could not address this issue. While filling the annular space with a low-permeability material is a desirable goal, the process of grouting during pullback is not recommended. Research and testing of grout materials with controlled delayed set times and grouting procedures should be required prior to such a recommendation. At this point, the potential risks of failure to complete the installation outweigh the perceived benefits of more reliably filling the borehole with a bentonite-cement grout. The risks of failure would impact the Corps of Engineers, Levee Boards, and the general public, as well as the contractors and pipeline operating companies.

Grouting of the annular space upon completion of the bore should also be addressed. The grouting pressures required to expel the drilling fluid must exceed hydrostatic pressures, because the drilling fluid pressure in the annulus must equal or exceed hydrostatic pressure. The grouting pressures must be lower than the overburden pressure or critical pressure required to initiate hydraulic fracturing. To increase the likelihood of uniform grout distribution around the pipe annulus, the use of perforated grout tubes attached to the pipeline has been suggested. After the grout is pumped through the tubes, they would be abandoned in place. This process would increase the difficulty and risk of failure of the pullback operation and could adversely impact corrosion resistance of the pipeline. This procedure was not tested as part of the CPAR field evaluation. Additional research to help establish the reliability of this grouting procedure may be beneficial.

A grouting procedure that may be viewed as a compromise may hold promise and is recommended. In this procedure, grouting tubes would be inserted as far as possible into the borehole after the pipe is pulled back. The grout mixture would be pumped into the annulus through these tubes until grout returned to the surface at the entry or exit of the pipeline. Grouting pressures must be carefully controlled to minimize risks of hydrofracture. This process may not be completely effective in dispelling drilling fluid and providing a low-permeability, solid barrier to seepage. However, the results should be beneficial if carried out carefully. This procedure is recommended as an added insurance measure at both ends of the pipeline.

In addition, the composition and hydraulic conductivity of the soil-drilling fluid mixture should be tested prior to construction to determine the in-place resistance to seepage provided by the mixture. It may be determined that the hydraulic conductivity of the soil-bentonite-water mixture is sufficiently low (lower than the surrounding natural soil) to minimize potential for seepage along

this pathway. These tests should be performed using the actual drilling fluid mixture(s) planned for use on the project, with varying percentages of bentonite and natural soils to bracket the planned or expected field conditions. This approach would also necessitate field quality control tests to ensure that the drilling fluid mixtures used for construction were the same as those tested.

Seepage blankets or berms (antiseepage devices)

Seepage blankets and berms have been used for many years to increase the factor of safety against piping and erosion along the landside toe of levees. Design of seepage blankets and berms is covered in EM 1110-2-1913 (Headquarters, Department of the Army (HQDOA) 2000). Some form of these features could be used on the landside entry and exit points of pipeline crossings for the same purpose, i.e., to reduce the risk of piping and erosion along the pipeline that could undermine the levee or its foundation. However, the specific criteria in EM 1110-2-1913 calls for installation of a drainage fill with an annular thickness of 0.457 m (18 in.) around the landside third of the pipe. This is not feasible with HDD pipeline installation.

Instead, it is recommended that a seepage analysis be performed during design of the crossing. If the hydraulic gradient at the landside entry/exit points exceeds the maximum allowable gradient, a landside seepage blanket should be evaluated. If the provision of the seepage blanket increases the factor of safety against piping to an acceptable level, it may be an economical insurance feature. To achieve its design function, the blanket would not have to extend great distances on either side to the pipeline, but could rather be a small, localized surface feature with gentle slopes to aid in levee maintenance. Depending on design requirements, the seepage blanket might add only very small cost to the project, yet provide significant benefits. The evaluation should be performed using actual soil properties, site conditions, and geometry.

Riverside cutoffs or collars

Riverside cutoffs or seepage collars may be considered for projects with exit points on the riverside of levees. For projects that enter and exit on the landside of opposite bank levees, riverside cutoffs are obviously not applicable. Seepage barriers, rings, or cutoffs are addressed in EM 1110-2-1913 (HQDOA 2000). The benefits of and need for seepage barriers or collars have been questioned. Poor compaction has been cited in EM 1110-2-1913 as a cause of piping failures with these devices, and their use is discouraged in the manual. If considered, seepage collars should be evaluated during design using actual site conditions, soil properties, and geometry. However, quality control must be meticulous to ensure that design objectives will be met. Specifically, the materials, mixture, placement, and compaction are all critical design elements. The materials and mixture should ensure low hydraulic conductivity, low shrinkage, and long-term stability. Placement and compaction must ensure intimate contact around the full pipeline circumference, without damage to the pipe. Laboratory tests of the hydraulic conductivity of the materials and mixture should be required. In addition, hydraulic conductivity tests of the system may be beneficial. This could be accomplished in

the lab using a small-scale model of the system, i.e., the mixture placed and compacted to design specifications around a tube to simulate the pipeline. The collar must extend for a sufficient distance around the pipeline to provide an effective impediment to seepage. Dimensions can be established by sequential seepage analyses with different trial dimensions.

Closure Devices

Closure devices are required in EM 1110-2-1913 (HQDOA 2000) for all pipes that penetrate the embankment or foundation of a levee. Flap valves or gate valves are recommended and automatic devices are described with design guidance provided in EM 1110-2-1413 (HQDOA 1987). Closure devices (valves) could serve a critical purpose in an emergency and should be considered with regard to pipelines beneath levees. Valves are required for liquefied petroleum pipelines by U.S. Department of Transportation regulation, Part 195, Section 260(e), at water crossings longer than 30.48 m (100 ft). Valves are not required on gas pipelines since there is no danger of spills.

Relief Wells

Relief wells have been proposed and used on a number of projects involving HDD; however, relief wells are not considered necessary under normal circumstances. The objective of proposed relief wells has been to vent the high drilling fluid injection pressures and avoid fluid pressures that exceed earth and groundwater pressures. The directional drilling process uses relatively high drilling fluid pressures and flow rates to the injection nozzle. These reported pressures have caused concerns about hydrofracturing. However, it should be understood that these pressures are quickly attenuated within a short distance of the nozzle. In the tests conducted by ERDC, and in those conducted by Delft Geotechnics (Luger and Hergarden 1988), the pressures measured in the annular space between the pipe or drill stem and the borehole wall were significantly lower than the nozzle pressures. In the ERDC tests, pressures in the annular space were only 323.83 to 358.28 kN/m² (47 to 52 psi), even for internal pressures as high as 2,411.5 kN/m² (350 psi). Excess pore pressures as recorded by the piezometers were less than or equal to 6.89 kN/m² (1 psi), and these excess pore pressures dissipated rapidly. Based on these results, relief wells are not considered necessary for venting drilling fluid pressures. Relief wells may be effective for dissipating high seepage pressures on the landside toe of levees during high-water events. This application is well documented and different from their use for venting drilling fluid pressures.

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14. ABSTRACT Applications for permits to drill beneath levees are increasing in permitting offices of the U.S. Army Corps of Engineer Districts. This report provides a basis for consistent and science-based consideration of these permit applications. It describes methods of horizontal directional drilling (HDD) beneath levees and lists the types of geotechnical and other data that are essential to judging the safety of proposed drilling for infrastructure modifications and installation of utilities. Critical considerations include setback distances, levee toe stability, thickness and integrity of the top stratum, and other geotechnical parameters. Data provided for vertical and horizontal permeabilities, top stratum thickness, hydraulic gradient at levee toe, and other parameters are based on experience in the U.S. Army Engineer Districts, Vicksburg and St. Louis, and the California Department of Transportation. In appropriate geotechnical settings with appropriate operational care, utilities can be installed beneath flood-control levees using HDD without compromising the integrity and function of the levee.					
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